Viscosity control of zein processing with sodium dodecyl sulfate☆

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Abstract

Zein, the predominant protein in corn, may be used as an alternative to various commercial plastics. Plastics produced from zein tend to be brittle, so plasticizers such as triethylene glycol (TEG) and water were used in this study to alleviate brittleness. When zein is blended with water and subjected to heat and shear in a torque rheometer, zein readily generates aggregates that produce a rapid increase in viscosity. This rapid increase in viscosity is manifested as a torque increase, which can be detrimental to industrial processes such as extrusion. The primary objective of this study was to control the viscosity rise during torque rheometry by adding known amounts of water, TEG, and/or sodium dodecyl sulfate (SDS), a known protein denaturant. Our findings with torque rheometry showed that water alone allowed zein to generate higher molecular weight species in approximately 1 min. Varied combinations of TEG and water delayed the torque rise to 2–4 min. When SDS was added to zein and combined with water and TEG, it significantly delayed the viscosity increase in a linear relationship dependent on the amount of SDS added. Because extrusion is a standard method for processing plastics, the second objective of this study was to assess the mechanical properties of extruded, SDS-modified zein. To accomplish this, zein was blended with a fixed amount of water and TEG with varying amounts of SDS. The mixtures were subjected to extrusion processing on a single-screw extruder equipped with a 2 mm round die, and the resulting rope was pelletized. One half of the weight of pellets was re-extruded through a 2 cm ribbon die, and the other half was freeze-ground and compression molded. The mechanical properties of tensile bars from the compression mold and those cut from the ribbon die were evaluated at either 50 or 70% relative humidity on an Instron with a crosshead speed of 50 mm/min. Tensile strength and Young's modulus diminished, whereas elongation increased with increasing amounts of SDS. Therefore, the addition of SDS did not improve the strength of the tensile bars, but it did improve the ductility. The results from torque rheometry and the mechanical testing of extruded products show that the addition of SDS to zein blends of water and TEG can be used to develop an acceptable formulation for both processing and end-use requirements.
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1. Introduction

Zein, the predominant protein in corn, is a potentially high-value coproduct of the bio-ethanol industry. According to recent reviews on zein (Shukla and Cheryan, 2001; Lawton, 2002), zein can be used as an alternative to various petroleum-based commercial plastics. Extrusion is the standard method for producing plastics. In order for zein to be extruded, plasticizers are typically employed to overcome the brittle nature of zein. Water has been shown to be an effective plasticizer for zein (Madeka and Kokini, 1996; Lawton, 2004; Selling et al., 2004). Unfortunately, water has been shown to cause zein to aggregate rapidly in a torque rheometer when it is used as a plasticizer (Selling et al., 2004).

Numerous publications present the effects that SDS and other detergents have on protein structure (Jaenicke, 1967; Reynolds and Tanford, 1970; Takeda et al., 1993). SDS is amphiphilic containing both a polar head group and a hydrophobic tail on the same molecule (Reynolds and Tanford, 1970). The charged head group can either bind electrostatically to the oppositely charged amino group of the protein or the alkyl chain can interact through hydrophobic bonding to the nonpolar groups either on the surface or in the interior of the globular protein. According to Reynolds and Tanford (1970), the binding of SDS to protein is primarily hydrophobic in nature and is independent of ionic strength.

Several studies have been made on the solubilization of water-insoluble zein in aqueous solution using SDS (Deo et al., 2003; Moore et al., 2003; Ruso et al., 2004). By understanding how surfactants denature proteins and how this denaturation can be minimized, the findings can be used to develop an in vitro test to screen surfactant mixtures prior to in vivo skin irritation testing for personal-care products.

Research has not been done on the interaction of SDS on zein under semi-dry conditions with a water content of up to 15%. Our objectives are: (1) investigate the use of SDS to control viscosity increases of zein plasticized with water and triethylene glycol (TEG) when subjected to torque rheometry; (2) assess the mechanical properties of extruded, SDS-modified zein.

2. Materials and methods

2.1. Materials

Commercial yellow zein (FC 4000) was obtained from Freeman Industries, Inc., Tuckahoe, NY. This zein, lot F400002317C, had an as-is proximate analysis: 14.14% nitrogen (Dumas), 3.4% moisture, 1.80% fat, 0.10% fiber, and 1.45% ash. Chemicals and electrophoresis materials were purchased as follows: TEG, 99%, and SDS, 99%, Aldrich Chemical Co., Milwaukee, WI; broad range molecular weight standards, Bio-Rad Laboratories, Hercules, CA; NuPAGE, Novex high-performance, pre-cast, 4–12% gradient bis–tris gel, Invitrogen, Carlsbad, CA; Coomassie Brilliant Blue R-250, Sigma, St. Louis, MO. All other chemicals and reagents used in this study were of reagent grade.

2.2. Torque rheometry

Blends of Freeman zein with water content ranging from 0 to 15% and/or 17% TEG that were combined with varying amounts of SDS were subjected to torque rheometry on a Haake Fisons, Rheocord 90, using the 600 series mixing bowl (Thermo Electron Corp., Madison, WI). The rheometer was equipped with high shear roller rotors. The bowl temperature was held at 90 °C and rotor speed set at 50 rpm. The temperature of the blend while being sheared was not controlled.

Moisture content of the supplied zein was measured daily for each test evaluation and would vary between 3.4 and 3.6%. Distilled water was used to adjust moisture content to the desired level. Studies were conducted using water as a plasticizer for zein where the added water was varied from 0 to 15% (dry basis). Percentages of added water, TEG, and SDS were each based on the amount of dry zein. TEG was evaluated in the range 15 to 17%, whereas SDS was varied from 1 to 5%. TEG and water combinations were also tested with SDS where the TEG was 17% and added water varied from 3.3 to 7% (dry basis) and the SDS was varied from 1 to 5%. A typical composition for a zein blend consisting of 7% water, 17% TEG and 5% SDS was prepared by adding 4.2 g water, 10.2 g TEG, and 3.0 g SDS to 60 g zein (dry basis).

Zein was treated with the selected reagents, and the blend was initially stirred with a spatula to pro-

vide a crude mixture. Sixty g of this zein composite were used to fill the chamber of the torque rheometer. It took approximately 4 min to fill the chamber. The start time ($t = 0$) for all tests was 1 min after complete addition. The torque curves acquired were smoothed using 1.5 min moving averages. Individual torque values were 1.5 min averages.

2.3. Extrusion of zein blends

Zein was blended with the desired amounts of SDS (i.e., 0, 2, 5, and 10%), 10% TEG, and additional water to adjust blend to 10% total moisture by slowly adding each component while mixing at a low speed on an Hobart mixer for 10 min. The blends were each extruded with a Brabender Model PL2000 (South Hackensack, NJ) single screw extruder with a 30:1 L/D screw having a 3:1 compression ratio. This extruder was fitted with a single hole, 2-mm diameter die, 7-mm long for producing a rope extrudate. Heating zones were 65, 90, 90, and 80 °C, respectively, for the feed section, zone 1, zone 2, and die. The screw was set at 60 rpm after startup. Rope extrudates, after cooling, were pelletized shorter than 1 cm using a Killion chopper (Cedar Grove, NJ). One-half the weight of each extrudate was re-extruded through a ribbon die having 5.08 cm width and 0.5 mm height. The extruder conditions for ribbon production were: zone 1, 65 °C; zone 2, 85 °C; zone 3, 85 °C; die, 100 °C; 9 rpm. Dumbbell specimens were cut from the extruded ribbon, parallel to flow, using a punch press NAEF Model B, No. 1738 (NAEF Press & Dies, Inc., Bolton Landing, NY) producing a tensile bar with dimensions 78 mm long, 13 mm wide at widest point, a gauge length of 25.4 mm with width of 4.0 mm, and a thickness of 0.5 mm.

The other one-half of pelletized rope extrudate was freeze-ground with liquid nitrogen on a Wiley mill and the resulting powder subjected to compression molding on a Carver, Model C press (Wabach, IN). The ground powder (1.5 g) was molded into a dumbbell-shaped tensile bar 63.5 mm long, 9.5 mm wide at the widest point, a gauge length of 7.6 mm with width of 3.2 mm, and a thickness of 3.2 mm. For compression molding, the material was held at 121 °C and 34.5 MPa for 20 min after which time the mold was allowed to cool to room temperature. These conditions provided a tensile bar with no visible remnants of the starting powder.

Mechanical properties of the SDS-modified zein tensile bars from the Carver press and those cut from extruded ribbon were evaluated after 1 week storage at either 50 or 70% RH on an Instron (see analyses).

2.4. Analyses

2.4.1. Polyacrylamide gel electrophoresis (PAGE)

SDS-PAGE was performed with NuPAGE, 4–12% gradient bis–tris gels. For our system, samples were dissolved in 0.055 M Tris, pH 6.8, 7.0% glycerol, and 5 M urea. Addition of urea was used to facilitate dissociation of protein aggregates (Takagi and Kubo, 1979). A 2.0% SDS solution was added to the buffer only for those samples that were not processed with SDS. Molecular weight standard used was SDS-Dalton broad range kit consisting of myosin (200 kDa), beta-galactosidase (116.25 kDa), phosphorylase *B* (97.4 kDa), bovine serum albumin (66.2 kDa), ovalbumin (45.0 kDa), carbonic anhydrase (31.0 kDa), Kunitz soybean trypsin inhibitor (21.5 kDa), lysozyme (14.4 kDa), and aprotinin (6.5 kDa). A Novex, X Cell II Mini Cell, electrophoresis cell (Invitrogen, Carlsbad, CA), was used with a tank running buffer of 0.025 M Tris, 0.2 M glycine, and 0.5% SDS. Electrophoresis was performed at room temperature at 200 V until the bromophenol blue tracking dye reached the bottom of the running gel. The gels were stained with Coomassie Brilliant Blue R-250 according to the method of Fling and Gregerson (1986). Stained gels were destained with a mixture of 18% ethanol and 8% acetic acid. The destained gels were then preserved with a solution containing 5% each of glycerol and acetic acid in water. Gels were scanned with UN-SCAN-IT gel, version 5.1, Automated Digitizing System (Silk Scientific Corp., Orem, UT). Protein stained bands were scanned along with the molecular weight standards where the mobilities of the standards were used to estimate the molecular weight of the zein control and processed zein products.

2.4.2. Tensile properties

Tensile properties were determined using an Instron Model 4201 tensile tester equipped with a 1 kg load cell. The thicknesses of the tensile bars were measured at five different locations with a micrometer (Model No. 49–63, Testing Machines, Inc., Amityville, NY). A gauge length of 2.54 cm was used with an extension rate of 50 mm/min. Tensile test runs were performed on

multiple ribbon and bar samples that were stored for 1 week at 50 and 70% RH. Mean values for each process are reported. The moisture content for those ribbon and bar samples were measured by heating the samples in a hot air oven at 105 °C for 1 h followed by cooling in a vacuum dessicator over Drierite.

2.4.3. Statistical analyses

The experimental design was a completely randomized design (CRD) with unequal replication consisting of two zein formulation treatments, two relative humidity levels, and four SDS surfactant levels performed on two replicates in quadruplicate.

The three dependent variables tensile strength, elongation (%), and Young's modulus were examined for ribbon and bar zein formulations at two relative humidity levels (50 and 70%) and four added SDS surfactant levels (0, 2, 5, and 10%). The means of these dependent variables were examined as a function of SDS (%) for each zein formulation × humidity level combination (Ribbon-50, Ribbon-70, Bar-50, and Bar-70) using weighted regression techniques. Weighted regression was based on the mean of replicated x-values (SDS) corrected by a weighting factor (1/variance) to reduce the influence of highly variable observations. Confidence intervals on the mean predicted values of tensile strength, elongation (%), and Young's modulus from the four equations were calculated at the 95% level and used to compare the SDS levels within a formulation × humidity combination. Predicted mean values of tensile strength, elongation (%), and Young's modulus at the four different SDS levels whose confidence intervals do not overlap were considered to be significantly different from one another within each formulation × humidity combination.

3. Results and discussion

3.1. Impact of SDS on torque rise

When mixed in a torque rheometer, water will cause zein to aggregate that results in a rapid torque rise as shown in Fig. 1. When TEG is combined with water, the amount of water needed to induce aggregation is reduced (Selling et al., 2004). The torque traces for zein with various amounts of TEG and water are shown in Fig. 1. With 17% TEG, either used alone or in combi-
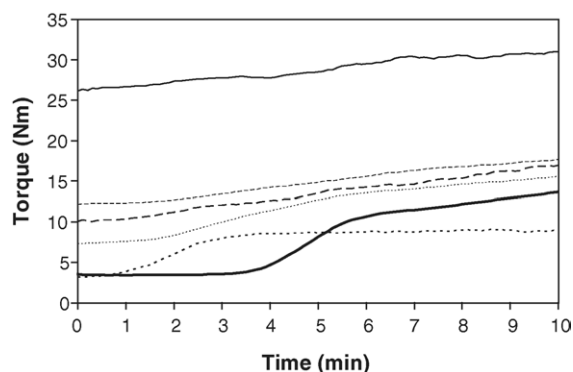

Fig. 1. Effect of TEG and water on torque rise for zein blends. Line/composition designations: (—) 17% TEG; (- - -) 17% TEG, 3.3% H_2O; (···) 17% TEG, 3.9% H_2O; (▬) 17% TEG, 7% H_2O; (_ _ _) 10% H_2O; (.....) 15% H_2O.

nation with 3.3% added water, there is a relatively constant increase in torque. This same pattern is observed with 10% water used alone. However, when 3.9% water or higher is added to 17% TEG, there is a rapid increase in torque. This rapid increase, with torque rise taking place in approximately 1 min, is also seen when 15% water alone is used. With the combinations of TEG and water, the rapid increase takes place within 2–4 min into the run.

When SDS is added to zein in combination with water and TEG as plasticizers, the SDS decreases the efficiency of mixing by prolonging the process time (Fig. 2). When the effects of TEG and water on the first derivative of torque rise for each of the zein blends
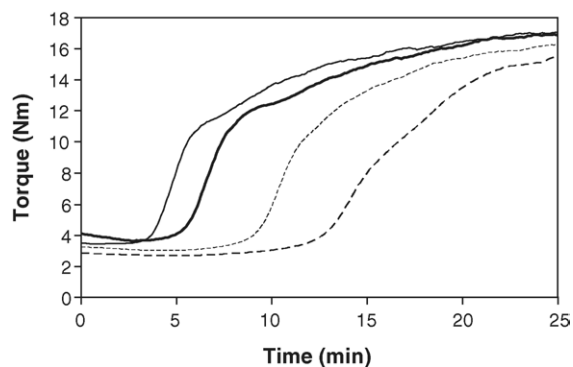

Fig. 2. Effect of SDS on torque rise for zein, TEG and water blends. Line/composition designations: (—) 17% TEG, 7% H_2O; (▬) 17% TEG, 7% H_2O, 1% SDS; (- - -) 17% TEG, 7% H_2O, 2.5% SDS; (_ _ _) 17% TEG, 7% H_2O, 5% SDS.
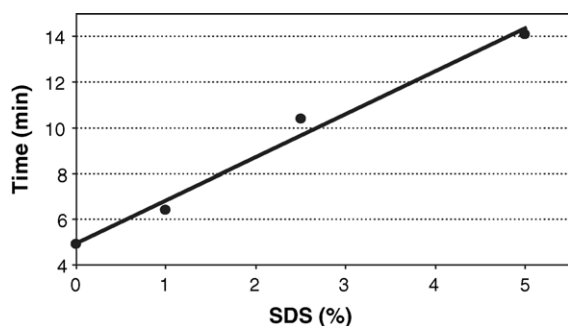
Fig. 3. Plot of the onset time for maximum torque rise vs. % SDS added to zein, TEG, and water blends. Linear relationship is defined by $y = 189.07x + 4.93$, where $x = \%\,SDS/100$ and $y =$ torque rise with $R^2 = 0.9843$.

in Fig. 2 are evaluated, the rate of change in torque decreases from 0.38 Nm/min (5.1 min) for 0% SDS, to 0.36 Nm/min (6.4 min) for 1% SDS, to 0.31 Nm/min (10.4 min) for 2.5% SDS, to 0.22 Nm/min (13.9) for 5% SDS. A plot of the rate of torque rise versus SDS (%), not shown, results in a linear regression defined by $y = -3.269x + 0.387$ with an $R^2 = 0.9924$, where $x = SDS\ (\%)/100$ and $y =$ torque rise (Nm/min). Danno and Hoseney (1982) hypothesized that, in their flour-water system, flour protein has a net positive charge, which, because of its repulsive forces, makes the protein hydrate faster. By adding low levels of SDS, the SDS either neutralizes or shields the charge causing the protein to hydrate slowly.

When the onset time of the torque rise, extrapolated as time of maximum torque rise (y), is plotted versus the amount of SDS added, a linear relationship is obtained that is defined by $y = 189.07x + 4.93$ with $R^2 = 0.9843$, where $x = SDS\ (\%)/100$ and $y =$ torque rise (Nm/min) (Fig. 3). An explanation of the SDS effect on torque may be that the SDS is simply acting as a lubricant in the early states of mixing so that it is natural that when more SDS is added, the longer the onset time. This type of behavior is not uncommon in plastics mixing where additive may be concentrated at the mixer wall until it is incorporated into the melt.

Published research performed on polyvinyl chloride (PVC) demonstrates that PVC produces torque curves with very similar shapes to ours when processed on similar equipment (Chen et al., 1995; Tomaszewska et al., 2004). In those studies, the rapid torque rise was attributed to gelation. Gelation is defined as that pro-

cess where the small particles of PVC begin to melt, and the polymer chains then entangle to form micro-crystalline domains. The micro-crystalline domains of PVC are analogous to protein aggregates. The processing parameters, temperature, shear rate, and the presence and type of additives can modify the time when gelation occurs.

We speculate that similar processes are taking place with zein subjected to torque rheometry. After initial loading, when the torque is low and relatively flat, the zein is beginning to absorb the water and/or TEG. At a certain temperature and shear rate, the zein denatures and forms entanglements and micro-crystalline domains (aggregates) leading to a rapid increase in torque. SDS is known to interact with zein (Ruso et al., 2004) and is widely used to inhibit protein aggregation. Because of this, it is reasonable to hypothesize that the SDS added interacts with the zein protein and slows the rate of aggregation that is being induced by the plasticizer(s) and processing. Eventually the effect that the SDS imparts is overwhelmed by the processing conditions resulting in aggregation and rapid torque rise. Further investigation is needed to establish better this possible mode of action of SDS on zein blends in a high shear environment.

3.2. Zein aggregation defined by SDS-PAGE analysis

During torque rheometry of zein blends with water and/or TEG as plasticizers either with or without addition of SDS, a torque rise was observed that we attributed to zein aggregation defined by increased molecular weight species upon SDS-PAGE analyses. SDS-PAGE was performed on a select grouping of those samples subjected to blending on the torque rheometer. The grouping selected consisted of zein blended with 10% water and 10% TEG either with or without 5% SDS. The dough-like blends were removed from the torque rheometer after specified times (Table 1), snipped into small pieces and the pieces, ground in a coffee mill. The ground blends were each subjected to SDS-PAGE analysis (SDS was only added to those samples that were not processed with SDS in the torque rheometer). Data from scanned gels are presented in Table 1 where the zein control possessed strong protein bands at 21 kDa with main band at 18 kDa, and minor bands at 12, 46, and 41 kDa. Those

Table 1
SDS-PAGE Gel Scans[a] of proteins from zein and torque rheometry processed zein

Molecular wt. (kDa)[b]													
Sample comp. zein	Process time (min)	319	133	111	79	51	46	42	39	21	18	12	9.7
Area of protein bands (%)													
Control	0	–	–	–	–	–	17.5	12.3	–	26.3	22.8	21.1	–
10% H$_2$O/10% TEG	3	12.4	8.0	8.0	6.6	5.8	8.8	5.8	8.0	9.5	8.0	11.0	8.1
10% H$_2$O/10% TEG	30	11.5	8.1	9.5	10.1	4.1	5.4	6.1	8.1	9.5	8.8	8.8	10.1
10% H$_2$O, /10% TEG, 5% SDS	6	–	–	–	17.5	–	17.5	16.3	12.5	17.5	18.7	–	–
10% H$_2$O, /10% TEG, 5% SDS	30	–	11.6	13.7	19.0	–	9.5	11.6	9.4	9.5	15.8	–	–

[a] Sodium dodecyl sulfate (SDS) polyacrylamide gel electrophoresis (PAGE) with no reducing agent; no SDS was added to samples processed with SDS.

[b] Average molecular weight for all protein bands in common in all lanes of zein either processed or unprocessed ± standard deviations of 0.2 for 9.7 to 18 kDa bands; 0.5 to 1.2 for 21 to 51 kDa; 1.1 to 3.6 for 79 to 319 kDa.

values are relative to our protein molecular weight standards. The two major bands represent the α components, that at 12 kDa is possibly β zein and those at 40 kDa represent dimers of the component proteins. Sets of data for zein processed with 10% water and 10% TEG for either 3 min or 30 min into the run where both gave evidence for torque rise, showed evidence of bands >300 kDa that we attributed to aggregation. Samples processed with the same amounts of water and TEG, but with 5% SDS, the sample processed for 6 min showed no torque rise and that processed for 30 min had torque rise. The former processed material had a protein band at ~79 kDa that was evident in all processed samples, whereas the latter had two protein bands >100 kDa. Our electrophoresis data showed that the presence of SDS modifies the amount of aggregation with protein bands >100 kDa that takes place during processing.

3.3. Mechanical properties of extrusion processed zein blends

As discussed in Section 2.3, zein was blended in a Hobart mixer with the desired amounts of SDS from 0 to 10%, 10% TEG, and additional water to make a total of 10%. Those blends were subjected to extrusion to generate rope-type extrudates. One half of the weight, subjected to re-extrusion through a ribbon die, cut into tensile bars, was designated as ribbon, whereas the other half was ground and subjected to compression molding to generate tensile bars was designated as bar.

As shown in Table 2, increases in SDS levels from 0 to 10% for each treatment × relative humidity combination tended to diminish tensile strength, increase elongation, and diminish Young's modulus. An exception to this tendency was noted with compression molded bars stored at 50% RH where increased SDS levels did not impact significantly on tensile strength, elongation, or Young's modulus. The greatest observed changes in the material properties recorded was storage of tensile bars of either ribbons or bars that were from zein processed with either 5 or 10% SDS and stored at 70% RH. In those samples, the tensile strengths were greatly diminished, the ductility based on elongation was significantly enhanced, and the rigidity based on Young's modulus was greatly reduced. Although not part of this statistical treatment data, ribbons stored either at 50 or 70% RH tended to have higher tensile strengths, lower elongation percent, and higher Young's modulus than the respective data sets of bars stored at the same humidities. The plasticized mass generated by extrusion of zein composites confers an orientation of zein molecules at the surface of the ribbon (unpublished results) that when the tensile bar is cut in the direction of flow the material properties differ when compared with ground zein composites that were plasticized during compression molding.

The moisture contents of ribbons and bars stored at 50% and 70% RHs, recorded in Table 3 are within the same population for either ribbons or bars. Bars stored at 70% RH at all SDS levels yielded elongations percentage significantly higher than all other treatments. Values increased with increasing amounts of added

Table 2
Predicted mean tensile strength, elongation, and Young's modulus values for zein tensile bars at different SDS levels for each treatment × relative humidity combination

Property	SDS (% added)	Trt × RH			
		Ribbon-50	Ribbon-70	Bar-50	Bar-70
Tensile strength (MPa)	0	34.6 a[a]	27.9 a	19.5 a	7.2 a
	2	23.0 ab	24.4 b	22.4 a	5.5 b
	5	21.8 ab	7.5 c	20.2 a	3.4 c
	10	14.8 b	3.9 d	17.3 a	1.9 d
Elongation (%)	0	5.7 a[a]	6.8 c	11.4 a	110.4 d
	2	5.6 a	9.8 b	11.4 a	253.5 c
	5	5.2 a	63.9 a	11.4 a	401.7 b
	10	7.1 a	93.8 a	12.8 a	581.6 a
Young's modulus (MPa)	0	1161.1 a[a]	817.1 a	299.8 a	60.5 a
	2	976.6 b	740.6 b	289.5 a	46.5 b
	5	882.2 c	179.5 c	287.3 a	32.5 c
	10	656.0 d	65.3 d	186.1 a	11.5 d

[a] SDS levels for each Trt × RH combination within a column followed by the same letter are not statistically different based on overlap of the 95% confidence intervals of mean predicted tensile strength, elongation, and Young's modulus.

SDS. This increase with added SDS was also observed with ribbons stored at 70% RH. Ribbons stored at 50% RH tended to have lower elongations than bars stored at the same humidity. In our zein blends, higher tensile strength resulted in lower elongation.

In contrast to our findings on the adverse effect of SDS on some of the mechanical properties of plasticized zein, Zhong and Sun (2001) observed increases in tensile strength and elongation for 5% SDS-modified soy 11S plastic. Those authors used an SDS weight percent based on total mass, whereas we used a SDS percent composite based on the starting weight of zein (dry basis). Calculation of the SDS weight % that they used in their formulations as a percent of 11S proteins on a solids basis equates to 4.5, 9.0, 18.0, and 45.0%, where only the latter percent impacted posi-

tively on both the tensile strength and elongation of their SDS-modified 11S plastics. At their highest SDS concentration, they observed that 11S protein generated a "loose and disordered structure" upon SDS modification and thermal denaturation. Therefore, contact area of the protein increased with consequent increase in intermolecular interactions (both polar and nonpolar). Improved intermolecular interaction of plasticized 11S protein-SDS complexes resulted in higher tensile strength and increased elongation than the control plastics with no SDS. Those same authors showed that all their SDS modifications reduced the water resistance of 11S. Those findings with increasing amounts of SDS would explain the significant decreases that we observed in Young's modulus for our ribbons and bars stored at 70% RH than those stored at 50% RH.

Table 3
Moisture contents (%) of ribbons and bars stored at 50% and 70% RH

Sample	SDS (%)	RH (50%)	RH (70%)
Ribbon	None	3.0	5.4
Bar	None	2.5	5.3
Ribbon	2	3.4	5.9
Bar	2	3.1	5.2
Ribbon	5	2.5	5.6
Bar	5	2.7	4.9
Ribbon	10	2.2	6.1
Bar	10	2.0	6.0

4. Conclusion

A linear relationship defined by $y = 189.07x + 4.93$ with $R^2 = 0.9843$, where $x = \text{SDS}(\%)/100$ and $y = \text{torque rise}$, was obtained when onset time of torque rise was plotted against SDS(%) added to zein, water, and TEG blends.

Mechanical properties (i.e., tensile strength, elongation, and Young's modulus) of zein processed with

SDS, water and TEG showed no improvement over similar zein blends without SDS.

Tensile strength and Young's modulus diminished in zein tensile bars with increased levels of SDS. Therefore, addition of SDS did not improve the strength and rigidity of the tensile bars, but based on increase in elongation percent, ductility was improved.

The results from torque rheometry and the mechanical testing of extruded products show that the addition of SDS to zein blends of water and TEG can be used to develop an acceptable formulation for both processing and end-use requirements.

Acknowledgements

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